London county council
Water supply of London

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WATER SUPPLY OF LONDON.

Joint Report of Sir Benjamin Baker, K.C.M.G., and
Mr. George Frederick Deacon.

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WATER SUPPLY.

Terms of reference to Sir Benjamin Baker and Mr. G. F. Deacon, dated 19th June, 1896—

1. There will be placed before the gentlemen in question the report and evidence of the Royal Commission, notes of evidence and speeches in the case of the Staines Water Bill, session 1896, all the reports of the chief engineer relating to the Staines scheme, and to the proposed Welsh supply, together with all plans, sections, estimates, and rainfall observations which he has made since 1890, and also the various reports of the Water Committee.

2. Sir B. Baker and Mr. Deacon are requested to consider the detailed proposals, plans, and estimates contained in the report of the chief engineer, dated 8th June, 1894, in connection with his scheme for obtaining water from the valleys of the Usk, Wye and Towy, and their tributaries, and to advise the Committee as to their suitability and sufficiency or otherwise.

3. The above-named engineers are requested to report on the question of the practicability and the cost of carrying out schemes of storage for providing 200 million, 300 million, and 400 million gallons per day respectively from the Thames, on the lines of the suggestion in the report of the Royal Commission.

4. The above-named engineers, taking into consideration the whole of the circumstances of the case, and having regard to the increasing rate of consumption per head, are requested to give their best advice to the Council as to whether or not it would be more advantageous to bring into London from the proposed Welsh sources than from the Thames, the additional quantity of water over and above the quantity at present supplied which will be required for the supply of the population of 11¼ millions, as estimated by the Royal Commission.

5. The following further question is also proposed upon which, if the engineers think it expedient, the Committee will be glad to have a short preliminary report—

The attention of the engineers being directed to paragraph 10, on page 13 of the report of 8th June, 1894, they are requested to advise generally as to whether in their opinion there is any other source of supply for the metropolis which presents such *a priori* advantages over either the scheme proposed by the engineer of the London County Council, or the suggested scheme of storage in the Thames valley, as would justify the selection of such other source in preference to both of the last-mentioned schemes.

Joint Report on the Water Supply of London.

Part I.—Introductory.

To the Water Committee of the London County Council.

Gentlemen,

In accordance with the terms of your reference to us, we have carefully considered the report and evidence of the Royal Commission of 1893, the notes of evidence and speeches in the case of the "Staines Reservoirs, &c., Bill, 1896," all the reports of the chief engineer of the London County Council relating to the Staines scheme and to the proposed Welsh supply, together with all plans, sections, estimates and rainfall observations which he has made since 1890, and also the various reports of the Water Committee.

In addition to the foregoing documents we have considered the report and evidence of the Royal Commission of 1869 (Duke of Richmond's) and numerous other documents bearing upon the question of whether a better source of supply could be found than either the scheme proposed by the chief engineer of the London County Council or the suggested scheme for storage in the Thames valley.

It is hardly necessary to remark that we have thus had an almost overwhelming mass of evidence and suggestions to deal with in considering the history of the water question up to the present date, but the investigation has been instructive as showing that owing to increase of engineering experience and the progress of science generally, many of the conclusions of the earlier inquirers demand important modifications, and that works which in the earlier days would have been considered by high authorities as of startling boldness, would now be accepted without comment as very ordinary and obvious affairs.

Inspection of proposed sites for reservoirs in Wales.

On the 7th of August, accompanied by the chief engineer and his assistant engineer, Mr. Seymour Rumble, we commenced our tour of inspection by proceeding from Abergavenny to Brecon, noting on the way the general features of the hills and streams and the proposed routes of the intercepting conduits to convey the rainfall to the Llangorse reservoir. On the following and subsequent days we made a thorough examination of the whole of the sources of supply proposed by the chief engineer, and the exceptionally dry state of the weather afforded a favourable opportunity of which we availed ourselves, for gauging the flow of some of the main streams, though we did not succeed in measuring the minimum flow for the year which had occurred some weeks previously.

Usk and Llangorse reservoirs.

Approximate figures as given in the chief engineer's report of 29th June, 1894*—

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
136,000 acres	Llangorse, 38,000 ...	2,800	595	182
	Usk (compensation) 6,500	530	733	

After gauging the flow of the Usk at Brecon we proceeded to inspect the proposed site of the eastern dam of the Llangorse reservoir, and found it unexceptionable as regards quality of rock foundation and in other important respects. Similar remarks apply to the western dam, though the foundation may possibly be a little deeper.

The features of the country surrounding the proposed reservoirs are similar in general character to those of the Vyrnwy and other areas of the Welsh hills in which reservoirs have already been established or commenced. The valleys and the lower parts of the hill slopes are occupied by pasture and farm lands, with widely scattered habitations, but the larger portions of the area consist practically of bare moorlands and rocks free from peaty or other objectionable deposits, and of a geological formation which ensures pure and soft water.

The points of engineering interest in connection with the Llangorse reservoir next in importance to the dams, are the necessary deviations of the Mid Wales and of the Brecon and Merthyr Railways. Near Tal-y-llyn junction the ground is somewhat low in relation to the proposed level of the water in the reservoir, but our inspection of the site satisfied us that this matter, as well as that of the railway and road deviations generally, is a question of estimate and not of practicability, and as such it has been fully taken into consideration.

Our next work was to thoroughly examine the alternative sites proposed for the dam of the Usk (compensation) reservoir, with regard to which in the present place it is only necessary to say that we found the conditions favourable, and that no engineering difficulty would arise in carrying out the proposed works.

Yrfon and Towy reservoirs.

Approximate figures.

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
102,600 acres...	Yrfon, 31,000 ...	2,850	606	135
	Towy (compensation), 3,000 ...	210	580	

* This report is the one referred to in the reference as the report of the chief engineer, dated 8th June, 1894. It was ordered to be printed on that day, but is dated 29th June, 1894.

Our route over the hills from Llangorse to the Yrfon and Towy afforded a fine general view of the whole country, and confirmed the opinion expressed by the chief engineer, in his report, as to the facilities afforded by this district for the construction of reservoirs which would be amply supplied with pure water from the neighbouring hills. We first inspected the site of the proposed dam and tunnel for diverting the upper waters of the Towy into the Yrfon, then proceeded to look into the conditions under which the compensating reservoir at Ystradffin would have to be established, and lastly inspected the site of the proposed great reservoir itself. In our opinion, no engineering risks or contingencies apply to any of the proposed works, but the extensive railway and road deviations involved will require very careful consideration and negotiation to minimise the opposition from those locally interested therein.

Edw reservoir.

Approximate figures.

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
17,000 acres	Edw, 4,400	570	700	18

From the high ground we obtained a good view of the reservoir, and, after examining the site of the dam, gauging the river, and noting the character of the rock as exposed in quarries and elsewhere, we found the same favourable conditions existing at Edw as in the cases previously inspected.

Ithon reservoir.

Approximate figures.

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
34,800 acres	Ithon, 9,000... ...	900	900	37
	Clywedog (compensation), 2,200 ...	240	800	

We first inspected the site of the dam across the Ithon, where, although no rock was visible in the bed of the river, the indications elsewhere showed that it would be found at a very moderate depth. After gauging the flow in the Ithon we similarly inspected the site of the Clywedog compensation reservoir and dam, following a route which enabled us to form an adequate conception of the general features of the country and of the incidental works at this spot.

Upper Wye reservoir.

Approximate figures.

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
22,000 acres	Upper Wye, 10,500	900	900	43

The conditions existing at the site of this reservoir were not appreciably different from those already referred to. Alternative sites for dams were examined, both of which afford good rock foundations, and the selection therefore would be determined by local considerations such as the flooding of a small village and relative cost.

The reservoirs above referred to include the whole of those proposed by the chief engineer in his report of June, 1894, but in accordance with the terms of your reference to the effect that we should consider whether any better sources of supply were available we extended our inspections to the Mid Wales and North Wales districts, and included Bala lake as well as the reservoirs proposed by Mr. Bateman in 1865 at Trefeglwys on the Tarannon and the rivers Carno, Clywedog and Dulas, tributaries of the Severn, which it was proposed to intercept for the service of that reservoir, as well as the sites for reservoirs at Garthbibio and Llanerfyl on the river Banw, a tributary of the Severn, and on the Nant-e-Eira, a tributary of the Banw.

We also visited the works in progress for the supply of Birmingham on the river Elan, a tributary of the Wye, and the completed works for the supply of Liverpool on the Vyrnwy, a tributary of the Severn.

The Bateman reservoirs.

The particulars of these areas were stated by the late Mr. Bateman as follows—

Catchment area.	Reservoirs.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level (lowest) feet O.D	
130,572 acres ...	35,500	4,600	500	219

It is to be noted that the Vyrnwy area has since been abstracted by Liverpool from the ground covered by Mr. Bateman's scheme.

On the 14th and 15th August we inspected the site of Mr. Bateman's proposed Trefeglwys reservoir, which is placed in a wide flat-bottomed valley narrowing somewhat at the point where the long earthwork dam was to have been constructed and again widening out below. We inspected also the sites of the dams for the other reservoirs forming part of Mr. Bateman's scheme.

We have not made any detailed studies or estimates of this source of supply, because our personal inspection and a general consideration of the conditions of the case satisfied us that although a sufficient supply of good water could doubtless be obtained in this district, the economical advantages would be in favour of the proposals of your chief engineer.

Bala Lake and River Tryweryn.

(Particulars submitted by Mr. Price-Williams.)

Catchment area.	Reservoir.			Daily supply to London, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
220,000 acres... ...	92,240	5,266	625	430

This scheme had previously been investigated for the purposes of Liverpool.

On the 17th August we inspected the site of the proposed dam at Bodwenni, about 2¼ miles below Bala Lake, and found the conditions favourable for such a work. We also inspected the small town of Bala (1,800 inhabitants) and the villages and railways in the valley, and found no serious objection to their submergence, as everything could be re-instated at a higher level.

We have been favoured by Mr. Price-Williams with a detailed report upon the scheme, including his estimate of the cost and available supply. We are of opinion, however, that whilst this project would offer no advantages over that of your chief engineer, the increased distance from London would render the cost greater.

As affording a scale to measure the magnitude of the works proposed for the supply of water to London, it may be interesting to record the following particulars respecting the works now in progress for Birmingham and those completed for Liverpool, both of which were inspected by us in the course of this inquiry.

Elan reservoirs.

(Birmingham.)

Catchment area.	Six reservoirs.			Daily supply to Birmingham, million gallons.
	Capacity, million gallons.	Area (aggregate) acres.	Lowest top water level, feet O.D.	
45,503 acres	17,947	1,505	822	75

Vyrnwy reservoir.

(Liverpool.)

Catchment area.	Reservoir.			Daily supply to Liverpool, million gallons.
	Capacity, million gallons.	Area, acres.	Top water level, feet O.D.	
23,500 acres	13,000	1,121	825	40

The lake districts of Cumberland and Westmorland.

A project of Messrs. Hemans and Hassard for the supply of London from the English lakes was laid before the Duke of Richmond's commission in 1867. This district has also been investigated for the purposes of a supply to Liverpool, but the river Vyrnwy in North Wales was found to be preferable. Manchester has since appropriated Thirlmere in Cumberland.

The two elements which appear to us to make it unnecessary to consider this project further are the great distance from London, and the fact that, like the valley of the Thames, the lake district consists largely of residential property, and is a pleasure resort.

Dartmoor.

We are generally familiar with the physical character of the Dartmoor district in relation to its capacity for water supply and reservoir construction. The valleys do not permit of the formation of reservoirs approaching in capacity those already referred to in Wales, and the cost per million gallons stored would probably be greater, while the total volume of water available at the necessary altitude would be much less. The distance from London moreover is considerably greater. Under these circumstances we have not thought it worth while to make more detailed enquiry.

Part II.

Detailed consideration of the Welsh project proposed by the chief engineer.

The chief engineer's scheme is divided into two main portions—

A.—The Usk and Llangorse sources for the supply of 200 million gallons a day to a reservoir at Elstree.

B.—The Wye sources for the supply of 200 million gallons a day to a reservoir near Banstead.

A.—The Usk and Llangorse sources.

The principal feature of the Usk and Llangorse scheme is the exceptionally fine site for a great reservoir afforded by a basin in the old red sandstone formation, at the bottom of which the Llangorse lake at present lies. The outlet of this lake is the Afon Llynfi, a tributary of the Wye, and across this stream the principal dam for the formation of the Llangorse reservoir would be constructed. The surface of the water would be about 93 feet above the present lake, and the available capacity of the reservoir would be no less than 38,000 million gallons. The area naturally contributing to the lake is only 9,000 acres, which in relation to the magnitude of the basin is small. But the chief engineer proposes to supply the enlarged lake, not only from its natural drainage area, but by means of conduits which will intercept and divert to it the waters of other areas. The conduit extending towards the east will convey water from an area of 25,000 acres of the Black mountains, at present draining to the left bank of the river Usk, and that extending towards the west, being bifurcated, will pass along both banks of the Usk for the purpose of intercepting about 87,000 acres at present contributing to the upper waters of that river.

The chief engineer's scheme, as laid down in his report of June, 1894, provides in addition a large reservoir on the Usk near Trecastle, in which the upper waters of that river would be stored and discharged in a uniform and continuous stream only varied by overflow during floods. The compensation water thus given to the main stream of the Usk was to be supplemented by a further discharge lower down the river from the Llangorse reservoir. The aggregate of these two quantities, and the smaller quantity to be discharged down the Afon Llynfi to the Wye as compensation for the abstraction of water now supplied direct to and from the Llangorse lake, was to be so proportioned as to amount to one-third of the discharge available for London; and, inasmuch as the impounded floods would form by far the largest portion of the supply to the reservoirs, we find that this continuous flow of compensation water would not be less than three times the natural flow of the stream towards the end of a dry season, while in some parts of the river it would be double this amount.

The provision thus made would therefore abundantly compensate the main river, but it would not supply the tributary streams below the level of the intercepting conduits, and some of these are so important that the question of supplying part of the compensation water to them by means of independent reservoirs was discussed between us, and we understand that the chief engineer concurs with us in thinking that such reservoirs should be constructed where reasonably practicable. The chief engineer has therefore had the ground examined and has provided us with supplementary information on this point. In considering the question we have allowed for the construction of such reservoirs.

A peculiarity of the Usk and Llangorse project is the large proportion of the supply to be conveyed to the main reservoir by artificial means; but we find that although the cost of the aqueducts necessary for this purpose is much greater than in most projects of the kind, that cost is counterbalanced by the exceptionally favourable conditions under which the great reservoir at Llangorse may be constructed. With the conduits as proposed some of the most turbid flood water would be rejected; but the volume thus lost has been fully taken into consideration in computing the available discharge.

In estimating the yield of the various districts we have assumed the correctness of Mr. G. J. Symons' rainfall gaugings. The gauges fixed under his superintendence are sufficient in number, and observations extending over two years have afforded, by comparison with the records of old gauges in the neighbourhood, sufficient data for forming a trustworthy estimate of the mean rainfall over long periods.

The results of our independent calculations have satisfied us that with this rainfall, and with the reservoirs originally proposed by the chief engineer and those for compensation to the tributary streams which he has since added, the Usk and Llangorse areas may be depended upon to yield after giving abundant compensation to the streams a supply to London of not less than 181 million gallons a day.

In order to increase this quantity to about 200 million gallons, the chief engineer has proposed in his report to construct a reservoir on the Edw, a tributary of the Wye. We find that this reservoir will yield for London about 16 million gallons a day, and will therefore bring up the available total for this part of the scheme to about 197 million gallons a day.

It is not necessary, in the first instance, to carry out such further work; or even to expend the whole of the money required to complete the aqueduct for a supply of 181 million gallons to London, as it is proposed to divide the portion of each main aqueduct under pressure into three independent conduits which may be constructed as they are required.

B.—*The Wye sources*, including the Yrfon, Towy, Ithon, Clywedog and Upper Wye reservoirs.

The supply, thus far considered, of about 200 million gallons a day to London may, if additional water is at any time required, be supplemented from other reservoirs to be constructed on the Wye and its tributaries, as proposed by the chief engineer.

The compensation waters to be given to the rivers affected by such additional reservoirs would be in the same proportion to the supply as that already set forth in the case of the Usk and Llangorse

areas, and substantially the same also as that now given from the Vyrnwy reservoir, and provided to be given from the Elan reservoirs by the Act under which they are being constructed.

The first reservoir in this second part of the chief engineer's scheme is to be constructed on the Yrfon, a tributary of the Wye. In addition to compensation water, it would yield 121 million gallons for London, and nearly the whole of the available rainfall would flow into it without the use of intercepting conduits.

At the time of constructing this reservoir, or at any subsequent time, the yield may be increased by means of a supply from the river Towy, which falls into the sea near Carmarthen. The additional water would pass through a tunnel constructed from the Towy valley to the Yrfon valley, and the abstraction would be compensated for by a reservoir on the Towy. These works would add 44 million gallons a day to the available yield of the Yrfon reservoir, and thus bring it up to a total of 165 millions.

Next in the list comes the Ithon reservoir, which from its own drainage area will yield the necessary compensation and 28 million gallons a day for London. After the construction of an independent compensation reservoir in the adjoining Clywedog valley, this quantity from the Ithon would be increased by 9 million gallons a day.

On the upper waters of the Wye the last reservoir proposed by the chief engineer would be constructed, and this we find may be depended on to yield for London 46 million gallons a day.

It thus appears that while the rainfall as now ascertained will enable the works proposed by the chief engineer in the Usk, Llangorse and Edw valleys to yield for London very nearly 200 million gallons a day, it will ensure from those he has proposed in the remaining valleys about 248 million gallons a day, should such an additional quantity ever be required, but as we are not asked, and do not think it necessary to take into consideration the construction of aqueducts for more than 400 million gallons a day, we have thought it desirable to simplify the question by the omission of the Ithon and Clwyedog reservoirs, which would yield together 37 million gallons a day, and would cost per million gallons more than any of the others. Thus modified, the various instalments of the chief engineer's scheme for an ultimate supply, if ever required, of 400 million gallons a day, might be executed in the following order—

Works to be constructed.	Supply to London, million gallons a day.	
	Each instalment.	Aggregate.
Usk and Llangorse sources—		
1st instalment—Usk and Llangorse reservoirs with aqueduct complete for 200 million gallons a day (except portions under pressure which may be divided into three instalments) and Elstree service reservoir	66⅔	66⅔
2nd instalment—Second portion of aqueduct under pressure	66⅔	133⅓
3rd instalment—Edw reservoir and third portion of aqueduct under pressure	63⅔	197
Wye sources—		
4th instalment—Yrfon reservoir with aqueduct complete for 200 million gallons a day (except portions under pressure which may be divided into three instalments) and Banstead service reservoir...	69⅔	266⅔
5th instalment—Towy reservoir, tunnel and aqueduct ...	66⅔	333⅓
6th instalment—Wye reservoir and aqueduct	66⅔	400

We need hardly remark that if found expedient the above order of execution of the different instalments may be varied, and the supply from the Wye sources be executed first. Further detailed studies of the Wye project must be undertaken before the relative merits of the two schemes can be definitely settled.

Estimated cost of works, land and easements.

We have now in accordance with the terms of this reference to consider the estimates of the chief engineer for the proposed Welsh supply.

As regards the first additional supply of 200 million gallons of water to London, we will assume that whether the Usk and Llangorse or the Wye sources were resorted to, the aqueduct would follow the line adopted by the chief engineer for the Usk and Llangorse project, and deliver into a reservoir at Elstree.

On the basis of detailed estimates forwarded to us in June, 1896, including the subsidiary compensation reservoirs already referred to, the cost of the different instalments of the 197 million gallons per day from the Usk and Llangorse sources delivered into a terminal reservoir at Elstree would be as follows—

1st instalment of	66⅔	million gallons		£11,427,193
2nd ,,	66⅔	,, ...		989,969
3rd ,,	63⅔	,, ...		1,594,968
				£14,012,130

The above sum includes £982,000 for the service reservoir at Elstree and 10 per cent. for contingencies, but nothing for filters and connection with existing distributing pipes, which, including 10 per cent. for contingencies, the engineer estimates at £3,435,300.

As regards the sum of 14 millions sterling we have fully considered the details and have thought it desirable to increase the estimates in some instances, but in others we think a saving will be effected.

We have added the cost of further compensation reservoirs on the tributaries of the Usk, and the result of the various adjustments is to bring our estimate of the total cost of the works to deliver 200 million gallons a day into a reservoir at Elstree for distribution in London nearly to the same figure as that proposed by the chief engineer.

As regards the second sum of nearly 3½ millions sterling we think the estimate will prove to be in excess of the real requirements. We have considered how far this estimate would be common to the Welsh scheme and to any scheme for pumping an equal quantity of water from the Thames. The sum included by the chief engineer for filters might be necessary for filters of the area required for Thames water, but experience of the filtration of mountain water shows that it is greatly in excess of the expenditure required in connection with the Welsh scheme. Having regard to all the circumstances we think that this estimate of 3½ millions somewhat reduced in amount may be fairly assumed to be common to the Welsh scheme and to any scheme for the supply of Thames water, and we shall therefore omit it from any comparison we may make between the two.

Assuming the first part of the scheme to be modified by carrying out works for the supply of 200 million gallons a day from the Wye sources, instead of from the Usk and Llangorse sources, without varying the line of aqueduct or the Elstree reservoir, the cost of the several instalments would be as follows—

1st instalment of 66⅔	million gallons	...	...	... £10,215,292
2nd „ 66⅔	„	...	...	... 1,759,968
3rd „ 66⅔	„	...	...	... 1,924,969
				£13,900,229

The ultimate cost of the alternative schemes treated in this manner is thus practically the same, but that of the first instalment of the Wye project is materially less, and there is a probable advantage in the latter arrangement, as the Usk and Llangorse sources now appear to yield about 1½ per cent. less than the 200 million gallons a day, while the yield of the Wye scheme even after the omission of the Ithon and Clywedog, as in the above estimate, is in excess by about 5½ per cent. We also think that the latter estimate allows a margin for the purchase of land and easements considerably in excess of that provided in the case of the Usk and Llangorse sources.

We have checked the chief engineer's estimates of the cost of obtaining a further supply of 200 million gallons from the Wye sources with a reservoir at Banstead-downs. On the assumption that the first supply is taken from the Usk and Llangorse, we do not appreciably differ in our results though for reasons already stated we think the estimate may be reduced by the omission of the Ithon and Clywedog reservoirs.

Part III.

The Thames Supply, and the Proposed Storage Reservoirs at Staines (Royal Commission Report, 1893), and Staines Reservoir, &c., Act, 1896.

The third reference to us relates to the practicability and the cost of carrying out schemes of storage for providing 200 million, 300 million and 400 million gallons per day respectively from the Thames, on the lines of the suggestion in the report of the Royal Commission, 1893.

As laid before the Royal Commission, this project—commonly known as the Staines reservoir scheme—was limited to 300 million gallons a day, and the main conclusion drawn by the Commission was as follows (paragraph 182, page 72)—

> "We think that regulations could be framed under which the quantity we suggest "could be taken, not only without reducing the flow of the river on the rare occasions of "exceptional drought to the present minimum, but in such a way as to secure that the "volume of water left in the river at these times would be substantially greater than it is "under existing conditions."

The Commissioners had before them the statement and evidence of Messrs. Hunter and Fraser on these points. They appear to have approved the principle of the project, but did not commit themselves to the mode of working it.

We have made ourselves familiar with the areas upon which it was proposed to the Royal Commission to construct these reservoirs. As regards their physical features, they are entirely suitable for the suggested works, but it must be borne in mind that such reservoirs would be wholly artificial, that is to say, the interiors would be excavated and completely surrounded by retaining walls or embankments. They would therefore differ widely from the reservoirs to be formed among the Welsh mountains by the damming up of entrances to valleys. The cost per unit of water impounded must therefore be very much higher. Still for reservoirs of the kind they would not be unduly expensive, and their functions would differ widely from those of ordinary impounding reservoirs. We observe that since the date of the Royal Commission, parts of the areas have been occupied by buildings, and other parts by a cemetery and a sewage farm, and as will appear later on, we think a much larger area of land will be required than was contemplated by the projectors.

We have divided our enquiry and observations as follows—

(1) Concerning the sufficiency or otherwise of the works included in the project as laid before the Royal Commission, to yield stored water to the extent and at the times intended by the projectors up to 300 million gallons a day, and the application of the same conditions to the supply of 400 million gallons a day.

(2) Concerning the extent to which, when the several expenditures have been incurred, the scheme will be efficient—

A. *As regards the condition of the supply at those times when the water would be sent to the filters direct from the Thames.*

B. *As regards the influence of the project upon the flow of the Thames.*

(1.) *Concerning the sufficiency or otherwise of the works included in the project as laid before the Royal Commission to yield stored water to the extent and at the time intended by the projectors up to 300 million gallons a day, and the application of the same conditions to the supply of 400 million gallons a day.*

The intention of the scheme as laid before the Royal Commission was to provide storage reservoirs near Staines, and "the complete scheme," to use the words of the Royal Commission (paragraph 86, page 33)—

> " is intended to provide for the taking of 300 million gallons a day for supply, and still " to leave 200 million to flow over Teddington Weir."

It is to be observed that the Royal Commission came to the conclusion that the gaugings at Teddington Weir were inaccurate. With this we agree, but we fear they do not afford any trustworthy data for an adjustment, which can only be effected by the adoption of material changes in the mode of gauging. Moreover we know what the nominal 200 or 2,300 millions at Teddington means in other parts of the river, and all our remarks will apply to whatever actual figures those nominal quantities are in future found to represent.

It is further stated in the report of the Commission, as follows (paragraph 86, page 33)—

> " It is proposed that no water shall be taken from the river during the first 15 days of " any flood, and the pumping charges have been made out on the assumption that four of " such floods may occur in a year, and that the water drawn from store during the 15 days " shall be replaced again by pumping in 20 days."

On reference to the statement of Messrs. Hunter and Fraser (Royal Commission Appendix C 66), we find that the definition of a *flood* is a flow of 2,300 million gallons a day at Teddington Weir.

The conditions, therefore, as laid before the Royal Commission, may be shortly summarised as follows—

A volume of 300 million gallons a day to be drawn for filtration and supply.

(*a*) Direct from the river, except during the first 15 days of a flood exceeding 2,300 million gallons a day at Teddington, and to such an extent only as will not reduce the flow of the river below 200 million gallons a day at Teddington.

(*b*) At all times not available for drawing wholly or partly from the river under (*a*), the whole or necessary portion of the water to be drawn from storage reservoirs. Such storage reservoirs to be 40 feet deep, the lower 10 feet to be charged from the river by gravitation (Q. 11,254), the upper 30 feet by pumping, the pumping power being sufficient to return to the reservoirs in 20 days the volume provided to be drawn from them during the first 15 days of any flood.

It is desirable in the first instance to test the scheme by assuming it to be in operation during a year of low rainfall, and then to ascertain whether the storage so determined will suffice for years in which great floods occur. The year 1893, in which the report of the Commission was made, was a year of drought, and may be conveniently used for the first purpose. The supplies dealt with by the projectors are 184, 235 and 300 million gallons per day respectively, and for these supplies the total storage given is 6,000, 10,000 and 18,000 million gallons respectively. On the same basis, for a supply of 200 millions a storage of 7,000 to 8,000 millions would be required, but we find that if the excess of the dry summer supply over the mean for the year, which amounts during the period of pumping from stock to 5·6 per cent., be added, and if a proper allowance be made for unavailable bottom water, and a proper reserve for cleansing and repairs, a total reservoir capacity of at least 10,000 million gallons would have been necessary during the drought of 1893.

In order to provide an average supply during the same year of 300 million gallons a day 311·8 millions per day would have to be supplied during the period of pumping from the reservoirs in the dry season. On the method of the projectors the total reservoir capacity provided to supply this quantity would only be 20,000 million gallons, whereas we are satisfied that not less than 28,000 millions would be necessary.

The chief object of the reservoirs is to act as settling tanks in which the suspended impurities contained in the water—largely derived from the river, as will be shown later on, in a turbid state—will be deposited, and not conveyed to the filters. It is clearly necessary, therefore, that a space towards the bottom of each reservoir should be reserved for the collection of solid matter, and for the preservation undisturbed of the lower water which always contains an abnormal proportion of suspended matter derived from the water above, and which, when such reservoirs are low, contains also an abnormal proportion of life. For this purpose we have provided one-eighth of the total depth, though we have considerable doubt whether this would prove to be sufficient. Even in ordinary impounding reservoirs it is well known that the quality of water drawn from below is inferior to that drawn from near the surface, and that the impurity increases as the surface is lowered. In depositing reservoirs the necessity for avoiding water near the bottom is imperative. In order, moreover, that periodical cleansing and repairs may take place, reserve reservoirs will be required.

These considerations involve increase in the constructional capacity as compared with the available capacity of the storage reservoirs.

We find that to ensure the supplies during the summer of 1893 corresponding with 200, 300, and 400 million gallons a day respectively on the average of the whole year, and adopting approximately the same size for each reservoir as in the scheme laid before the Royal Commission, the numbers of reservoirs and capacities shown by thin type in the following table would be required. For the sake of comparison the numbers and capacities given in the project as laid before the Royal Commission, with the increases we consider necessary, have been shown in thick type.

Table A.

Average daily supply to London during the year. Million gallons.	Number of consecutive days during which any water would be supplied from the reservoirs.	Average daily supply to London from river and reservoirs during the periods in column 2. Million gallons.	Reservoirs in use. Available contents required for storage of water for filtration and supply to London during dry period and floods. Million gallons.	Reservoirs in use. Constructional capacity allowing for evaporation and bottom impurity. Million gallons.	Reservoirs in use. Number.	Reservoirs in use. Constructional capacity of each. Million gallons.	Reservoirs in reserve for cleaning, etc. Number.	Reservoirs in reserve for cleaning, etc. Constructional capacity of each. Million gallons.	Total constructional capacity of reservoirs. Million gallons.
1	2	3	4	5	6	7	8	9	10
174·5	**97**	**184**	**5,116**	**6,000**	**3**	**2,000**	**Nil**	**Nil**	**6,000**
200	114	211·2	6,282	8,000	4	2,000	1	2,000	10,000
222·1	**119**	**235**	**8,609**	**10,000**	**5**	**2,000**	**Nil**	**Nil**	**10,000**
288·7	**165**	**300**	**17,526**	**18,000**	**9**	**2,000**	**Nil**	**Nil**	**18,000**
300	167	311·8	19,726	24,000	12	2,000	2	2,000	28,000
400	217	412·1	37,740	46,000	23	2,000	3	2,000	52,000

It is to be observed that for some reason, at present unexplained, the excess of the summer supply over the average for the year was unusually small in 1893, and that in most dry years column 3 would therefore show a larger excess over column 1 than in the above table.

We find further that the storage so determined as necessary during dry weather would have been sufficient throughout the last fourteen years to provide the required supply from stock during the first fifteen days of any flood or floods discharging on each of those days more than 2,300 million gallons at Teddington. Subject therefore to the doubt we have already expressed as to the sufficiency of our allowance of one-eighth of the depth of the reservoirs for unavailable bottom water, the thin type figures in the last column of the above table may be taken as the constructional capacity of the reservoirs necessary to fulfil the conditions laid down by the projectors of the scheme presented to the Royal Commission. It will thus be seen that the scheme as laid before the Royal Commission would fail—by reason of insufficient reservoir capacity—to ensure the yield of clarified water to the extent and at the times apparently assumed by the projectors. Concerning this there can hardly be any doubt, though there may be differences of opinion as to the extent of the deficiency.

There is another point connected with the construction of these reservoirs to which attention should be drawn. It has already been stated that the projectors in their scheme as laid before the Royal Commission gave to the reservoirs a depth of 40 feet, the lower 10 feet of which would be filled from the river without pumping. No provision seems to have been made for pumping back to the river the unsuitable water in the bottom of the reservoirs. The promoters of the Staines, &c., Reservoirs Bill, 1896, on their deposited plans show reservoirs to hold 2,500 million gallons with a depth of 30 feet instead of 40 feet, the bottom level being above the level of the Thames. In this case the average cost of pumping from the river must of course be greater than it would be if one-fourth of the depth were below the level of the river, and the area occupied by reservoirs of a given capacity must necessarily be about one-third greater.

The greater area of reservoirs required at a depth of 40 feet would involve the acquisition for the 300 million gallons scheme of about 40 per cent. more land than was contemplated by the projectors of the scheme laid before the Royal Commission, and if the reservoirs were reduced to 30 feet in depth the additional land required for both changes would be about 86 per cent. In respect of land, therefore, as well as reservoir capacity, we are of opinion that the provision made in the scheme laid before the Royal Commission is inadequate.

Apart altogether from the merits or demerits of the Staines project for the supply of any specific quantity of water, it is important to observe the very high ratio in which the necessary storage increases with the supply. Thus for an increase of daily supply from 200 to 300 million gallons—an increase of only 50 per cent.—the increase in the storage must exceed 180 per cent., and for an increase of daily supply of from 200 to 400 million gallons—an increase of only 100 per cent.—the increase in the storage must be 420 per cent.

Assuming that the rates in the projectors' estimates of expense are sufficient, but adding 10 per cent. for contingencies, as we have done in the case of the Welsh project, the cost of the works and the annual charges for pumping would be as shown in the following statement—

Table B.—STAINES RESERVOIRS PROJECT.

Capital cost of works and land on the basis adopted in the project as laid before the Royal Commission and applied to the thin type figures in table A, page 10.

Supply to London—Average for the year.	200,000,000 gallons a day.		300,000,000 gallons a day.		400,000,000 gallons a day.	
Particulars. (1)	Remarks. (2)	Capital cost. (3)	Remarks. (4)	Capital cost. (5)	Remarks. (6)	Capital cost. (7)
(1.) Land, easements, storage reservoirs, aqueducts, and incidental expenses at projectors' price, viz., £228·06 per 1,000,000 gallons stored, plus 10 per cent. contingencies	Constructional storage capacity, gallons. 10,000,000,000	£ 2,508,660	Constructional storage capacity, gallons. 28,000,000,000	£ 7,024,248	Constructional storage capacity, gallons. 52,000,000,000	£ 13,045,032
(2.) Pumping engines and buildings to pump water from river to reservoirs at £45 per P.H.P., plus 10 per cent. contingencies, calculated on rate of pumping being as 15 days duration of flood is to 20 days duration of pumping, or three-fourths of rate of supply lifted 30 feet. No reserve of pumping power allowed in original project, though after a dry summer the whole of the engines would be at work continuously for months together; for example, in the 300 million scheme from December 10th, 1893, to March 31st, 1894, a period of 112 days, only 29 days occur in which the engines would not be fully at work. We have therefore added to the engines and pumps— 25 per cent. in the case of the 200 million gallons scheme. 17 ,, ,, ,, 300 ,, ,, ,, 13 ,, ,, ,, 400 ,, ,, ,,	Horse power including reserve. 1,184 P.H.P.	58,608	Horse power including reserve. 1,661 P.H.P.	82,220	Horse power including reserve. 2,137 P.H.P.	105,782
(3.) Pumping engines and buildings to deliver water from filters into districts at £45 P.H.P., plus 10 per cent. contingencies. (Apparently a reserve of pumping power of 42 per cent. has been allowed in excess of the average power required)	17,959 P.H.P.	888,970	26,940 P.H.P.	1,333,530	35,918 P.H.P.	1,777,941
		£3,456,238		£8,439,998		£14,928,755
	The above sums include 10 per cent. for contingencies, but nothing for filters and connection with existing pipes, which items collectively would probably not differ in cost materially from the corresponding items in the Welsh project.					
	Annual Pumping Charges.					
(4.) (*a*) Pumping from river to reservoirs at 5s. per 1,000,000 gallons ...		4,570		9,431		15,435
(*b*) Pumping to town districts at 50s. per 1,000,000 gallons ...		182,500		273,750		365,000
		£187,070		£283,181		£380,435

In the above figures there is no charge for pumping foul water back to the river from portions of the reservoirs below the river level, nor is there any charge for the periodical digging out and cleansing always necessary.

We have accepted the rates for pumping brought before the Royal Commission, although those for pumping to town districts are below the present actual cost as set forth in the official returns.

In any comparison of the Staines project with the Welsh project, so much of the annual pumping charges as would be avoided by the Welsh project must obviously be capitalised on a proper basis.

(2) We have now to consider how far this expenditure would make the scheme efficient—

A.—*As regards the condition of the supply at those times when the water would be sent to the filters direct from the Thames.*

Under this head we have to state our conviction that the scheme as laid before the Royal Commission was based upon a misconception of the condition of the Thames water when the volume at Teddington is less than 2,300 million gallons a day, as compared with its condition when the flow is more than 2,300 million gallons a day. The limit of 2,300 million gallons is, we believe, entirely arbitrary, but it represents approximately, for a large portion of the river above Reading, the *top bank level*, or in other words the level at which the low-lying lands about the Thames begin to be flooded.

Above this level the discharging power of the river in relation to its sectional area increases more slowly, and the mean velocity may even decrease.

The process of deposition of impurities known as "sedimentation" occurs simultaneously with the scour, and the excess of one over the other is determined by the actual velocity and by the rate of change of velocity. We may reasonably expect therefore to find that the impurities in the raw river waters are often as great when the discharge is below as when it is above 2,300 million gallons a day, and we may further expect to find that very bad conditions occur during small freshets following upon comparatively steady flows, even though such freshets amount to only a small fraction of 2,300 million gallons a day.

We have now to ascertain how far these views are borne out by actual observation.

So far as we are aware, the only independent observations of the raw Thames water—as distinguished from the water after filtration—of sufficient frequency to answer the purpose, are those made by Dr. Frankland for the Local Government Board, and reported each month by the water examiner appointed under the Metropolis Water Act, 1871. Since May, 1892, Dr. Frankland has examined every month a sample of water collected from the Thames at Hampton, and has reported the number of microbes per cubic centimetre contained in such water. Whatever differences of opinion there may be as to the specific effect of the Thames microbes, it will be generally conceded that their numbers at different times form a good criterion of the relative condition of the water at those times, and of its suitability or otherwise for filtration without previous storage. A critical examination of these returns appears to us to support in a very significant manner the conclusions to which *a priori* reasoning on hydraulic principals would lead. It leaves no doubt that if the storage of Thames water is needed in any condition of the river, before filtration, that storage should be applied when the river is discharging very much less than 2,300 million gallons a day at Teddington, and it shows further that no conclusions as to the necessity for storage at any particular time based merely upon the discharge at Teddington at that time are trustworthy.

The number of returns of observations made by Dr. Frankland from May, 1892, to October, 1896, has been fifty-five. The highest number of microbes recorded on any one occasion in the same period was 56,630 per cubic centimetre, the lowest was 631, and the mean was 9,620. The highest number, 56,630, was recorded on the 15th January, 1894, being the seventh day from the beginning of a small flood which never reached 2,300 million gallons a day at Teddington. The discharge at the time was only 1,615 million gallons a day, but the water was described by Dr. Frankland as very turbid and pale brown. Throughout this flood—if the project had been in operation—this, the worst water in point of bacterial impurity observed during the five years, would have passed direct to the filters without storage, and therefore without any benefit whatever from the scheme.*

The next highest number of microbes was 50,040, collected on January 21st, 1895, the seventh day from the beginning of a high flood, which had then nearly reached its maximum and was discharging at the rate of 5,537 million gallons a day. This flood exceeded 2,300 million gallons a day at Teddington on 22 days, during the last seven of which the water would have been sent to the filters without storage, though as late as the 21st day (4th February, 1895) it stood fifth in point of bacterial impurity, and contained 34,220 microbes per cubic centimetre. The water was described by Dr. Frankland as turbid and pale yellow. The third sample in point of bacterial impurity was collected on the 8th October, 1896, being the first of only two days on which the flood exceeded 2,300 million gallons a day. The maximum flow was reached on the second day, and on the first the microbes numbered 39,760. This flood would have been avoided by the use of stored water. The fourth degree of bacterial impurity occurred on the 11th March, 1895, at the top of a flood reaching 2,602 million gallons a day, and lasting only three days. The microbes were 36,560, but in this, as in the preceding case, the flood would have been avoided by the use of stored water.

The next cases in order of number of microbes are the sixth and seventh (29,260 and 26,800 respectively). Neither of these would have been avoided by the project, but the eighth, with the smaller number of 20,080 microbes, occurred while the river was discharging 4,563 million gallons, and would therefore have been avoided.

Numbers 9 to 12 in order of bacterial impurity were all collected while the river was discharging less than 2,300 million gallons, the 9th, having 18,000 microbes, with a discharge of 1,778 million gallons, and the 12th having 14,630 microbes with a discharge of only 1,226 million gallons a day. The thirteenth in order of bacterial impurity, with the smaller number of 13,947 microbes, was collected on the fourth day of a discharge just before the highest part of the flood, which for eight days exceeded 2,300 million gallons, and on the day the sample was taken averaged 3,351 million gallons. The water of this flood would have been avoided. Contrast with this No. 14 on the 19th October, 1893, the last case we shall deal with, when the number of microbes was 13,790, almost exactly the same as in the great flood last named, though they were produced by a mere freshet of 645 million gallons a day, the water of which by the project would have been taken to the filters direct. This case did not directly follow dry weather, but was preceded by another freshet, reaching on the 11th October to a maximum of 856 million gallons, the water of which would therefore also have been taken direct to the filters without storage, though we may reasonably believe its condition during

* Since the above was written we have received the official water examiner's reports for November and December, 1896. From the latter report it appears that a sample taken on the 8th December, when the river was discharging at Teddington 3,944 million gallons a day, was found by Dr. Frankland to contain the enormous number of 160,000 microbes per cubic centimetre. A cubic centimetre is a cube the side of which is a very little greater than $\frac{3}{8}$ of an inch.

the first of the two freshets to have been much worse than during the latter, which fell within the fourteen worst cases.

To summarise the conclusions in a different way it appears that out of the whole number of 55 observations only five represent water which would be avoided by the scheme. In these cases the water contained on the average 32,077 microbes per cubic centimetre, while in another set of five the water would have passed to the filters direct, though it contained an average of 32,982 microbes per cubic centimetre.

Under these circumstances we are of opinion that Dr. Frankland's independent observations justify the view at which we have arrived on hydraulic considerations that the impurities in the raw river water are often as great when the discharge is below as when it is above 2,300 millions a day, and they undoubtedly indicate that if, for example, the project as laid before the Royal Commission had been in operation during the last five years, foul river water would have been supplied to the filters direct in about the same number of cases in which equally foul river water would have been avoided.

The present population draining into the Thames above the intakes of the companies is about 1,100,000, and is increasing at the rate of more than 8,000 per annum. We have visited a number of the works for the treatment of sewage at present established in connection with the chief centres of this population, and we do not anticipate any material improvement in the quality of the effluents, as although scientifically possible the cost would be practically prohibitory. We think, therefore, that notwithstanding the maintenance of the present inspection and stringency, the average quality of the effluent will remain very much what it is now, and it therefore follows that with the growing population the proportion of impurity to the volume of water must increase.

It has been very generally supposed that by the report of the Royal Commission the project for the construction and working of storage reservoirs as laid down by the projectors, and which we have thus criticised, was found to be sufficient, but the Commissioners in paragraph 134 have carefully guarded themselves against the consequences of any such misconception. That paragraph is as follows—

> " These being the facts, we are of opinion that by the construction in the neighbourhood " of Staines of reservoirs of adequate capacity into which water shall be pumped and stored " in times of excess to be used in times of deficiency, at least 300 million gallons a day may " be obtained for the supply of London. We believe this can be done without taking in the " more turbid of the flood waters and without injuriously diminishing the volume of the " river below the point of abstraction. To ensure the best results in both these respects the " taking of the water should be subject to strict regulations laid down by Parliament."

With the conclusions thus expressed we agree except as to the words " without injuriously diminishing the volume of the river below the point of abstraction," but as we have shown a satisfactory condition of the water cannot be secured by the scheme as projected if the water to be avoided is limited to the first 15 days of a flood exceeding 2,300 million gallons a day.

That regulations for the taking of water could be laid down by Parliament, which if strictly observed would secure the use of Thames water in its better conditions only is quite true, but such regulations would involve the construction of much larger and more costly reservoirs than those we have referred to as necessary to fulfil the conditions laid down by the projectors of the scheme, but to which conditions the Royal Commissioners did not commit themselves.

B.—*As regards the influence of the project upon the flow of the Thames.*

In an ordinary scheme of water supply the source of which is a pure mountain stream, the high floods, which may well be spared, are available for storage and use. By impounding such streams the dry weather flow is not reduced, but on the contrary is in all important cases greatly increased in virtue of the compensation water which the special Act requires to be given. By the conditions of the Staines project as laid before the Royal Commission, the whole of the water for storage must be taken from the river when the flow exceeds 200 millions gallons and does not exceed 2,300 million gallons a day, unless the latter volume has continued for more than 15 days.

This condition makes it necessary to draw the river down to the 200 million level at Teddington for long periods at a time.

During the last fourteen years the natural average weekly flow of the river has on no occasion fallen below 273 million gallons a day. This minimum occurred in 1896. After deducting the water taken by the companies the weekly average of the discharge at Teddington has only fallen to 200 millions a day in six out of the last fourteen years, and the average period during which it has remained so low during the fourteen years has only been seven days a year.

The Royal Commission do not specifically approve the proposal to permit the river to be pumped down to 200 millions for longer periods than at present. They say (paragraph 182)—

> " We think that regulations could be framed under which the quantity we suggest could " be taken not only without reducing the flow of the river on the rare occasions of exceptiona " drought to the present minimum, but in such a way as to secure that the volume of water " left in the river at these times would be substantially greater than it is under existing " conditions."

Here there is no reference to the effect of the project upon the duration of the minimum. *Cæteris paribus*, any increase of the volume of the minimum flow, however short the period, is some improvement, but the words " substantially greater than it is under existing conditions " can scarcely have referred to the mere bringing up of the extreme minimum to what, notwithstanding the existing pumping, is now the minimum, except on an average of seven days in a year, especially if during the remaining days of summer and autumn the flow were to be reduced to that minimum.

But such is the effect of the project.

Reverting to the conditions which would have obtained in 1893, if the project had been in operation, we find that the principal changes in the flow of the river would have been as follows.

Whereas the weekly natural flow of the river at Teddington never during that year fell below 281 million gallons, and after the deduction for pumping by the companies only fell to 200 millions on 28 days, the project for the supply of 200 millions to London would have brought that flow down to the 200 million limit on 153 days, while that for the supply of 300 millions would have done so on 185 days, and that for the supply of 400 millions on 223 days.

		Percentage of natural flow.	Duration of reduced flow.
As matters stood in 1893, the flow fell in consequence of pumping by the companies to or below ...	200 millions, or about	62 per cent.,	during 28 days.
If the 200 million scheme had been in operation, the flow would have fallen to	,, ,,	53 per cent.,	,, 153 ,,
If the 300 million scheme had been in operation, the flow would have fallen to	,, ,,	50 per cent.,	,, 185 ,,
If the 400 million scheme had been in operation, the flow would have fallen to	,, ,,	45 per cent.,	,, 223 ,,

It is not only in the dry years that serious changes would occur. There have been several years of approximately average rainfall on the Thames basin since 1883, when the records of gauging at Teddington were begun, the first of these, 1885, was more than 2 per cent. above the average, but the effect upon the river would have been as follows—

		Percentage of natural flow.	Duration of reduced flow.
As matters stood in 1885, the flow fell in consequence of pumping by the companies to or below ...	200 millions, or about	65 per cent.,	during 10 days.
If the 200 million scheme had been in operation, the flow would have fallen to	,, ,,	52 per cent.,	,, 95 ,,
If the 300 million scheme had been in operation, the flow would have fallen to	,, ,,	47 per cent.,	,, 127 ,,
If the 400 million scheme had been in operation, the flow would have fallen to	,, ,,	46 per cent.,	,, 134 ,,

The effect upon the river between the new intakes (situated probably above Bell-weir) and Teddington-weir, a length of 18 miles, requires consideration. In this length the water from about 26 per cent. of the whole area of the Thames basin down to Teddington is discharged into the river, and it was stated in evidence by the promoters of the Staines Reservoir Bill, 1896, that the natural flow over Bell-weir was about 71½ per cent. of the natural flow over Teddington-weir; and assuming this to be correct, 200 million gallons at Teddington-weir would in the absence of pumping between the two weirs, be equivalent to 143 million gallons at Bell-weir. But the conditions of the project, as laid before the Royal Commission, imposed no obligation upon the promoters with respect to the quantity passing over Bell-weir, and it would often happen that Bell-weir would be pumped down much below 143 million gallons, while the 200 millions was maintained at Teddington, by streams discharging into the Thames at intermediate places. For example, with the 300 million gallons scheme in operation, the average daily flow at Bell-weir during 167 days in 1893, would have been about 88 million gallons, and during some weeks it would have been still less. The reaches most affected would be those between Bell-weir and Penton-hook, and between Penton and Chertsey. If the condition were imposed that the river at Bell-weir should not be drawn below 143 million gallons, the reservoirs would have to be considerably enlarged.

The exact effect of these considerations depends upon the position of the intakes, but wherever they are placed above Staines the principle will be the same.

It has already been stated that during the last fourteen years the natural average weekly flow of the river has on no occasion fallen below 273 million gallons a day, and that after deducting the water taken by the companies, the weekly average of the discharge at Teddington has only fallen to 200 million gallons a day in six out of the last fourteen years. If the scheme for the supply of 200 millions to London had been in operation, the 200 millions minimum at Teddington would have been reached (for periods exceeding a week at a time) in eleven out of the fourteen years, while by the 300 million gallons scheme the river would have been similarly drawn down in all years.

The direct effect of this abstraction by reason of the extent to which it reduces the *level* of the water in the tidal portion of the river may not be of much importance, but the reduction produced in the velocity and scouring action of the ebb tide (caused by prolonging the dry weather flow in the manner involved in the Staines project) would in our judgment have a detrimental effect upon navigation and upon the sanitary condition of the river. Were large additional volumes of water abstracted from the Thames, extra expenditure would have to be incurred in dredging local deposits, and having regard to the fact that the abstraction of fresh water will in an exactly proportionate degree be accompanied by a corresponding increase in the volume of sewage effluent poured into the river at Barking and Crossness, it might be found necessary or desirable to discharge the additional sewage at some point lower down the river than the present outfalls.

The Staines Reservoirs, &c., Act, 1896.

It is proper to draw attention to the fact that since the finding of the Royal Commission an instalment of the Staines scheme—the "Staines Reservoir, &c., Act, 1896"—has already received the sanction of Parliament, but without the safeguards which the Commission recommended.

The Act as it stands provides that the main reservoirs shall be kept full to the greatest capacity so far as practicable; but no condition is imposed to prevent the water from being supplied to such reservoirs or direct to the town in any state of the river except when it is flowing less than 265 million gallons a day at Bell-weir, which is fixed as the equivalent of 200 millions at Teddington—some eighteen miles lower down—after allowing for the abstraction of 130 million gallons a day which the existing companies have power to pump from the river between the two places.

In laying the Staines scheme before the Royal Commission even the original projectors provided that no water should be drawn direct from the Thames during the first fifteen days of a flood exceeding the rate of 2,300 million gallons a day at Teddington, but the Staines Reservoirs Act, 1896, contains no such condition or any other provision in lieu of it. Moreover, the Act contains no limitation (except that set up by the limit of quantity to London) to the period during which the river may be pumped to its minimum, and the companies even by this small instalment of the project, providing only 35 million gallons a day for London, may increase the present maximum duration of the flow of 265 millions at Bell-weir from about 59 days to 105 days, or, with the permission of the Local Government Board, they may take 45 million gallons a day and thus increase the period of minimum flow to 117 days.

There is no doubt a serious difficulty in dealing piecemeal with the subject of storage reservoirs either on the Thames or the Lea, and we think that any provision for the better storage of the supplies which the companies at present have power to derive from the Thames and Lea, should be common to all the companies pumping from either of those rivers respectively.

Part IV.

Concluding observations.

In accordance with the terms of the reference we have reported on the suitability and sufficiency of the chief engineer's proposed Welsh supply, and on the practicability and the cost of carrying out schemes of storage for providing 200, 300 and 400 million gallons per day respectively from the Thames on the lines of the Royal Commission report. The result of our investigations has led us to increase somewhat the magnitude of the works required for the Staines project, and in the Welsh project to omit some reservoirs and include others for compensation purposes. Having done this, we think the projects and the costs per unit as fixed by the projectors are fairly comparable.

The Welsh scheme would deliver water of unexceptionable quality, as good, no doubt, as the waters of Loch Katrine, Thirlmere, or Vyrnwy. Neither Glasgow nor Manchester thinks it necessary to filter such water, but Liverpool does filter it, and the chief engineer, rightly, we think, proposes that London should do the same. As to which portion of the Welsh scheme should be first carried out we cannot, in the absence of the necessary details and surveys, offer a final opinion, but on the information before us, we think it probable that the Wye sources will prove the more generally advantageous.

If enlarged in the manner we have indicated the Staines scheme would, we think, supply the stated quantities of water, but the quality, in our opinion, would not always be that apparently intended by the Royal Commission, since water in which the impurities were as great as they are on the average during the first 15 days of a flood of 2,300 million gallons per day would frequently be taken into the reservoirs and even to the filters direct.

That the reservoirs would have a beneficial action in assisting the proper working of the filters we have no doubt, but we do not think any system of filtration, except a double and perfectly overlapping system, will at all times secure immunity from the passage of impure water, considering that in the words of the Royal Commissioners, with which we concur, "a new filter,* composed of perfectly purified sand, has little or no effect in producing either chemical or bacteriological purification."

Having reference to the character and extent of the present London waterworks, and to the length of time which must elapse before any radical alteration of the system of supply could be effected, it is clear that neither the Staines nor the Welsh scheme, in its entirety, nor the estimate for either project, applies exactly to existing circumstances, and the most important and generally useful part of the reference to us is therefore the instruction to take into consideration the whole of the circumstances of the case, and to advise the Council whether, in our opinion, it would be more advantageous to bring into London from the proposed Welsh sources than from the Thames the *additional* quantity of water over and above the quantity at present supplied.

In considering the question from a practical point of view it is necessary to remember that for the next ten or fifteen years, the Thames must be the chief source of supply, and that there is little reason to suppose it will ever be entirely abandoned as an alternative or contributory source. In 1911 the quantity of water required by London will not at the present rate of increase exceed the existing powers of the water companies, which include supplies of 165 million gallons from the Thames and 120 million gallons from the Lea and elsewhere, or 285 million gallons in all, so that as regards statutory power no difficulty need arise from the delay incidental to the adoption of a Welsh project, except such as may be inseparable from the present divided administration.

We will for the purpose of comparative estimates assume that whether the Welsh supply be adopted or not, there would, before that supply could become available, be 165 million gallons per day taken from the Thames. The question, therefore, is whether twelve or fifteen years hence, say in 1912, it would, on the whole, be more advisable to gradually increase that 165 million gallons as the growth of population might require, or to introduce a supply of 200 millions in one or more instalments from Wales, and to correspondingly reduce the quantity pumped from the Thames and other sources.

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* New in the sense of newly cleansed.

As regards capital expenditure, no figures are required to show that it must necessarily be more costly to bring water from Wales than from Staines, and further, whilst the Welsh scheme must be commenced earlier than the Staines, and be completed to the extent of one or two reservoirs and the greater part of one of the aqueducts before it becomes available, whilst the latter may be completed in smaller sections, the interest during the construction must be somewhat greater proportionately than the capital expenditure in the respective cases. On the other hand the working expenses would all be in favour of the Welsh scheme by reason of the cessation of pumping charges, and the reduced working charges on filters and settling reservoirs.

We have considered many alternative ways of presenting our views as to the respective costs of the two systems of supply, and have thought on the whole that the price per thousand gallons of water distributed would be the most generally understood unit of comparison.

In relation to this comparison it is to be observed that the Staines scheme can only be worked on the conditions laid down, if it is made to apply to the whole of the water drawn from the Thames, that is to say, not only to the increment of volume between the present and the later date, but to the original volume also. If it did not so apply, the reservoirs, in order to maintain a flow of 200 million gallons a day over Teddington weir, would have to be very much larger and more costly.

Let us suppose that either one, two or three instalments of one of the 200 million gallons Welsh schemes were brought to London in 1911, when the pumping from the Thames would be nearly the statutory maximum of 165 million gallons a day. A portion of the pumping expenditure on the Thames, and possibly on the Lea also, would immediately cease, and the present excess of pumping in dry weather would be relieved. The wet weather difficulty would also be removed, because turbidity would be confined to a much smaller quantity of water with which slower filtration could be practised, and if it were thought desirable that settling reservoirs should be constructed to prevent the choking of the filters during floods, their size would be insignificant by comparison with the huge storage reservoirs which the Staines scheme at present demands to prevent the fall of the river below 200 million gallons a day at Teddington.

If on the other hand an attempt were made to apply the Staines scheme as a general solution for the future, not only must it be applied to the various increments of supply after 1911, but to the whole quantity previously pumped also. If the necessary Act of Parliament were obtained in 1898, we think there would be no difficulty in securing Welsh water before 1911. In the alternative of the adoption of the Staines scheme the works must be ready by the same date and must have been constructed for the 165 million gallons a day, and for a small additional quantity to go on with increasing to 66⅔ millions plus that small additional quantity, in 1924, thirteen years later. We believe that such works would take about half as long to construct as the first instalment of the Welsh scheme, and we have apportioned interest on capital accordingly. The latter supplies from the Staines scheme (so far as it could be carried) might be extended in instalments of about 40 million gallons a day.

We will assume in the first instance that the whole of the 200 million gallons of Welsh water is brought to London in 1911, and that the pumping charges are proportionately reduced.

Upon these conditions, on the views of the Royal Commission as to increase of population and of demand for water, and on the assumption that interest and sinking fund can be provided for a rate of 3 per cent., we arrive at the following conclusions regarding the relative costs per 1,000 gallons of the additional supply from Wales and from the Thames—

(*a*) That until 1911 the question of the relative cost per 1,000 gallons does not arise.

(*b*) That in 1911 the supply from the Thames would probably be 165 million gallons per day, and from other existing sources 120 million gallons, being 285 million gallons in all, which is the total quantity for which statutory powers have been at present obtained. With the additional quantity of 200 million gallons from Wales this would suffice for London for a further period of 33 years after 1911, or until the year 1944, and additional supplies could be obtained from Wales as might be required.

(*c*) That with the Staines reservoir project, in the same year, 1944, the supply would be 365 million gallons from the Thames and 120 million gallons from other sources.

(*d*) Dividing the interval between 1911 and 1944 into three periods of 11 years each, we find that for the first period the extra cost of the purer and softer Welsh water would be less than 1d. per thousand gallons; for the second period less than ½d., whilst for the third period it would be practically nil.

The preceding figures would be varied if the 200 millions were brought from Wales to London in successive instalments, but not to an extent affecting the deductions to be drawn from them.

Our opinion as engineers as to what would be the "more advantageous" course to adopt, assuming the above estimates to be reasonably correct, is of course not worth more than that of others who are not engineers, but we have been asked to give our "best advice to the Council," and we therefore venture to make the following general remarks.

The Royal Commissioners observe (paragraph 178) that they "are well aware that a certain prejudice exists against the use of drinking water derived from the Thames and the Lea, because those rivers are liable to pollution."

On this we would remark that the two rivers are actually and seriously polluted, and it is impossible to foresee whether the prejudice on this account may not increase for the future. The Council have to consider, not what are the present views of the majority of the ratepayers, but what may possibly be the views of their successors, say 20 years hence, for it is the future rather than the present generation that would be most affected by any decision the Council may now make.

The whole history of the London water supply shows a steady and continuous demand on the part of the public for increased purity of water, and we have no reason to assume that the desire to get the purest water reasonably attainable will cease to grow. Experience elsewhere has proved that the quantity and quality of water insisted upon in any given place depend at least as much upon the "prejudices" and "sentimental objections" of the inhabitants as upon hygienic considerations.

To illustrate this we may state that in a recent water dispute, in which we were both engaged, evidence was adduced that it was the custom for whole families of colliers to use the same bath daily in order to economise hot water. No sentimental objections on their part, nor hygienic objections on the part of the medical officer of health, existed to prevent this being done, but we well know that in most cases sentimental objection to the use of water, even for ablutionary purposes, which has been slightly contaminated by another person is so strong as to impose upon public bodies the duty of supplying sufficient water for everyone to have a separate bath, cost being a secondary consideration. There can surely be little question that if individual members of the public could exercise the same choice as regards water for potable purposes they would select the least contaminated water reasonably attainable as they do when merely a bath is in question.

Happily the evidence brought before successive Royal Commissions as to the general quality of water at present supplied, notwithstanding the pollution of the source of the supply, relieves the Council from the necessity of adopting any heroic measure, such as the entire abandonment of the Thames and Lea in the interests of public health; but it does not relieve the Council from the necessity of giving due weight as regards any additional supply to the "prejudice" which the Royal Commissioners refer to in their report. No one acting for himself personally with regard to a water supply to his own country house would allow a small difference in cost to determine whether he should go to a pure spring or to a stream into which some other house drained, although the latter might be so remote that he could allege no better reason for his decision than "prejudice." It appears to us that in coming to a decision upon so vital and irrevocable a question as the additional supply of water to London for a long series of years, the safer course would be to act for future generations as our instinctive and deeply-rooted feelings in favour of pure water would lead us to act for ourselves. It is true that the results of chemical and biological researches in relation to filtered Thames water are eminently reassuring, but it is necessary to remember that science has not said the last word on this or any other subject.

In following the course suggested, entire consistency we venture to think would be preserved with the admittedly proper action of public bodies generally in matters relating to pure air and pure water. Thus the restriction of the heights of houses in streets of certain width, and the pecuniary loss thereby imposed upon owners is justified upon broad general principles, and not upon the number of bacteria observable in different streets. It is held reasonable also to insist upon certain minimum heights of rooms in new buildings as conducive to purity of air, although this involves increased cost; but it would be held unreasonable, except in extreme cases, to order the demolition of existing and otherwise good buildings because they did not comply with the same requirements. Similarly it might be considered unreasonable to dispense with the existing water supply from the Thames and the Lea, and at the same time to be quite reasonable to insist upon an unpolluted supply for future requirements, and this notwithstanding that some increase in cost may be involved.

It is hardly necessary to observe that the Royal Commissioners in their report recommend on hygienic grounds that the water should be delivered for consumption in as unpolluted a condition as large subsidence reservoirs, perfect filtration and the exercise of all possible vigilance in preventing unnecessary contamination of the Thames would admit, and *a fortiori* apart from the question of cost an initially unpolluted supply must have met their approval.

The Commissioners also acknowledge the existence of a "not unnatural sentiment against drinking water which though wholesome has been polluted at an earlier stage," and the strongest advocates of the Thames supply admit that the wholesomeness of such water depends upon efficient filtration which has not always been secured in the past.

Apart, however, from satisfying sentimental objections and hygienic doubts, the adoption of the Welsh project for additional supplies would have the further advantage of introducing a volume of soft water to London, and of leaving a corresponding body of land water in the river to dilute the sewage and to clear the bed and banks of deposits.

As regards the first point, we adopt the conclusion of the Duke of Richmond's Committee of 1869—"That for washing and for manufacturing purposes generally, soft water is preferable as more "efficient and economical, but there appears no means of expressing the amount of saving in a money estimate." We agree also that this advantage does not in itself render it "necessary" to go to a great distance for soft water. As regards the abstraction of water from the Thames there is even a greater difficulty in expressing the results in a money estimate, but we do not think any hydraulic engineer would question the serious disadvantage of extending the present period of minimum flow of 28 days in any year to more than 200 days.

Summarising our views generally "on the whole of the circumstances of the case," and therefore sometimes upon matters governed by personal feeling rather than by engineering principles, which we should not have ventured to do had the terms of the reference not imposed this duty upon us, we may state our general conclusions as follows—

(1.) That for the next ten or fifteen years the Thames must necessarily remain the chief source of supply for London.

(2.) That together with the wells and probably the Lea, the Thames will always be maintained as an alternative or contributory source of supply if for no other reason than that set forth by the Duke of Richmond's Commission, namely, the undesirability of any change by which the metropolis would become dependent upon a single source of supply which might be liable to accidental interruption.

(3.) That the evidence brought before the Royal Commission as to the quality of the existing supply when perfectly filtered shows that there is no reason for entirely abandoning the present sources of supply, though views differ widely as to the maximum quantity which may be taken from the Thames with impunity.

(4.) That the practical question for decision within the next year or two is whether twelve to fifteen years hence the additional supply shall come from the Thames or from Wales.

(5.) That the personal prejudices and sentiments of the public, rather than the opinions of engineers, chemists and accountants, are the most powerful factors in deciding such questions, and therefore it is not necessarily a wise course to accept the lowest tender and take an inferior article where water supply is concerned.

(6.) Personally, we should feel no hesitation in deciding that the *additional* supply of water should, as far as possible, come from Wales, because we should then, in our opinion, have had all reasonable regard both to true economy and to existing and future prejudices and sentimental or real objections to an initially polluted and subsequently more or less purified supply. We should in short be doing for the population collectively what we should be doing for ourselves individually in going to a pure spring, if there were one reasonably available, for our own domestic supply, although it might involve a little more trouble and expense.

(7.) The extra trouble and expense to individual households in London of getting the additional supply of water from the purest source available rather than out of the nearest stream would be insignificant compared with that willingly incurred by country residents and cottagers for the same object, since on the basis of the figures given in this report for the first 200 million gallons a day, it would involve an additional expenditure of less than a penny per week for an average household, whilst for the second instalment of 200 million gallons the Welsh water would be the cheaper of the two.

We are, Gentlemen,

Your obedient Servants,

BENJAMIN BAKER.

GEORGE F. DEACON.

Westminster, S.W.,
26*th March*, 1897.